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Over the last three years our work has centered in the areas of electromagnetically induced transparency and applications and the development of short wavelength lasers and radiation sources.

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Edward L. Ginzton Laboratory
Stanford University
Stanford, CA 94305

"RESEARCH STUDIES IN ELECTROMAGNETICALLY INDUCED TRANSPARENCY"

FINAL REPORT

FOR

THE AIR FORCE OFFICE OF SCIENTIFIC RESEARCH

AND

THE ARMY RESEARCH OFFICE

Contract F49620-92-J-0066

For the Period

15 December 1991 - 14 October 1994

Principal Investigator:

S. E. Harris

December 1994

I. INTRODUCTION

Over the last three years our work has centered in the areas of electromagnetically induced transparency and applications and the development of short wavelength lasers and radiation sources.

Our work on electromagnetically induced transparency is an outgrowth of earlier work on lasing without population inversion. The basic idea is to create a situation where atoms which are in the ground state do not interact with an electromagnetic field of a particular frequency. These atoms are essentially tabled and contribute to neither the absorption coefficient or to the refractive index of the medium.

Our work on short wavelength lasers has employed a new concept: the use of tunneling ionization to both create the target species and, at the same time, to create the hot electrons which will excite this species. As noted in the initial proposal for this contract, work on this project was a long shot. In the last several months we have been successful and have constructed a laser at about 30 eV with a gain of about exp (11).

This has been an unusually productive period for our research group. Not only have we demonstrated, for the first time, this new laser concept and new laser at 44 nm, but have also shown, in recent weeks, that electromagnetically induced transparency may operate under conditions where both lasers have comparable intensity. We now are certain that we may put strong laser beams through otherwise absorbing media. We have also shown that the spatial properties of these beams are well preserved and, in fact, have shown that a diffraction-limited image could be formed at the output of a medium which would otherwise have an absorption of exp (-6000).

Section II of this report will summarize the contributions which were made during the overall contract period, Section II lists publications which acknowledge this contract, and Appendix A gives the abstract for each of these publications. Before proceeding, we note that the work described here has been, and will continue to be, jointly supported by other agencies, primarily the Army Research Office, the Office of Naval Research, and, to some extent, the Strategic Defense Initiative Organization.

II. SUMMARY OF ACCOMPLISHMENTS

(1) A particularly exciting development during this contract period was the first demonstration of the use of femtosecond time scale lasers to create incoherent x-rays which extend beyond 1 MeV. We have found an energy conversion efficiency from laser energy to x-ray energy above 20 keV of about 0.3%.

(2) We have completed and published studies of the 96.9 nm laser in neutral Cs. This was the first laser to operate with its upper level above the continuum.

(3) We have completed an effort to generate very high-order harmonics using the ultra-high-power femotosecond system which was also used to produce the incoherent x-rays. As an outgrowth of this work we have noted the possibility that these high-order harmonics, to the extent that they are appropriately phased, will produce temporal structure under radiation on the order of 5×10^{-17} sec.

(4) We have made several improvements and developments toward the realization of a new Ti:Sapphire based femtosecond laser system. A new oscillator has been constructed which produces 804 nm pulses with durations as short as 20 fs and with peak powers as high as 500 kW. At the time of construction, these results represented the shortest duration pulses ever generated directly from a laser oscillator. Modeling of the dispersive intracavity components allows minimization of higher-order intracavity phase distortion. A high-modulation-depth, acousto-optic modulator allows intracavity power, self-phase modulation, and pulse bandwidth to be maximized without concurrent cw operation. Ray tracing of the laser resonator also reveals that cubic phase distortion can be eliminated in a laser

resonator by the correct choice of prism material and operating wavelength. This suggests the possibility of the construction of significantly shorter duration laser oscillators.

(5) The essence of lasers which operate without population inversion is the phenomena of electromagnetically induced transparency. This is a technique for making a media transparent with most of the atoms remaining in the ground state. Two publications demonstrated that this technique could work well and easily. In the first, an opacity of about $exp\ (-20)$ in Sr vapor was changed to $exp\ (-1)$. In a follow-up experiment, we were able to show that the same type of transparency could be obtained in a collisionally-broadened, rather than a lifetime-broadened, media.

(6) The concept of electromagnetically induced transparency with matched pulses was introduced. Prior to this work, it was realized that matched pulses would drive atoms into a population-trapped state. Here, it was shown that the atoms, in turn, would drive the electromagnetic field so as to produce matching pulses. It was also shown that the front edge of a pair of matched pulses would prepare the media, allowing lossless propagation thereafter.

(7) We have completed the construction of a first-of-its-kind ultrashort pulse laser system. The system is capable of producing 135-mJ, 35-fs, 800-nm pulses with near diffraction-limited beam quality.

(8) We have studied the dynamics of electromagnetically induced transparency and have observed, for the first time, group velocities as slow as c/160. We also have a tentative observation of the recently predicted adiabatons.

(9) As noted earlier, we have constructed a new type of short wavelength laser. The laser is based by tunneling ionization and electron excitation and lases at 44 nm.

III. LIST OF PUBLICATIONS

(15 December 1991 to 14 October 1994)

1. J. D. Kmetec, C. L. Gordon III, J. J. Macklin, B. E. Lemoff, G. S. Brown, and S. E. Harris, "MeV X-Ray Generation With a Femtosecond Laser," *Phys. Rev. Lett.* **68**, 1527-1530 (March 1992).

2. S. E. Harris, J. E. Field, and A. Kasapi, "Dispersive Properties of Electromagnetically Induced Transparency," *Phys. Rev. A* **46**, R29-R32 (July 1992).

3. C. P. J. Barty, G. Y. Yin, J. E. Field, D. A. King, K. H. Hahn, J. F. Young, and S. E. Harris, "Studies of a 96.9-nm Laser in Neutral Cesium," *Phys. Rev. A* **46**, 4286-4296 (October 1992).

4. J. D. Kmetec, "Ultrafast Laser Generation of Hard X-Rays," *IEEE J. Quant. Elect.* **QE-28**, 2382-2387 (October 1992).

5. B. E. Lemoff and C. P. J. Barty, "Generation of High Peak Power 20 fs Pulses from a Regeneratively Initiated, Self-Mode-Locked Ti:Sapphire Laser," *Opt. Lett.* **17**, 1357-1369 (October 1992).

6. S. J. Benerofe, G. Y. Yin, and S. E. Harris, "116 nm H_2 Laser Pumped by a Traveling-Wave Photoionization Electron Source," in *Vacuum Ultraviolet Radiation Physics*, edited by F. J. Wuilleumier, Y. Petroff, and I. Nenner (New Jersey, World Scientific, 1993), pp. 85-95.

7. C. P. J. Barty, C. L. Gordon III, J. D. Kmetec, B. E. Lemoff, and S. E. Harris, "Ultrashort High Peak Power Lasers and Generation of Hard Incoherent X-Rays," in *Proceedings of of the International Conference on Lasers '92*, edited by C. P. Wang (McLean, VA, STS Press, 1993), pp. 44-51.

8. C. P. J. Barty, B. E. Lemoff, and C. L. Gordon III, "Generation, Measurement, and Amplification of 20-fs High-Peak-Power Pulses from a Regeneratively Initiated Self-Mode-Locked Ti:Sapphire Laser," in *SPIE Proceedings on Ultrafast Pulse Generation and Spectroscopy*, (Bellingham, WA, Society of Photo-Optical Instrumentation Engineers, 1993), pp. 6-30.

9. B. E. Lemoff, C. L. Gordon III, and C. P. J. Barty, "Design of a Quintic-Phase-Limited Amplification System for Production of Multi-Terawatt 20-fs, 800-nm Pulses," in *OSA Proceedings on Shortwavelength V: Physics with Intense Laser Pulses*, edited by Paul B. Corkum and Michael D. Perry (Washington, DC, Optical Society of America, 1993), pp. 31-35.

10. B. E. Lemoff and C. P. J. Barty, "Cubic-Phase-Free-Dispersion Compensation in Solid-State Ultrashort-Pulse Lasers," *Opt. Lett.* **18**, 57-59 (January 1993).

11. J. J. Macklin, J. D. Kmetec, and C. L. Gordon III, "High-Order Harmonic Generation Using Intense Femtosecond Pulses," *Phys. Rev. Lett.* **70**, 766-769 (February 1993).

12. S. E. Harris, "Electromagnetically Induced Transparency with Matched Pulses," *Phys. Rev. Lett.* **70**, 552-555 (February1993).

13. Maneesh Jain, G. Y. Yin, J. E. Field, and S. E. Harris, "Observation of Electromagnetically Induced Phasematching," *Opt. Lett.* **18**, 998-1000 (June 1993).

14. J. E. Field, "Vacuum-Rabi-Splitting-Induced Transparency," *Phys. Rev. A* **47**, 5064-5067 (June 1993).

15. S. E. Harris, J. J. Macklin, and T. W. Hänsch, "Atomic Scale Temporal Structure Inherent to High-Order Harmonic Generation," *Opt. Commun.* **100**, 487-490 (July 1993).

16. J. E. Field and A. Imamoglu, "Spontaneous Emission Into an Electromagnetically Induced Transparency," *Phys. Rev. A* **48**, 2486-2489 (September 1993).

17. B. E. Lemoff and C. P. J. Barty, "Quintic-Phase-Limited, Spatially Uniform Expansion and Recompression of Ultrashort Optical Pulses," *Opt. Lett.* **18**, 1651-1653 (October 1993).

18. C. P. J. Barty, B. E. Lemoff, C. K. Gordon III, and P. T. Epp, "Multiterawatt Amplification of Ultrabroadband Optical Pulses: Breaking the 100 fs Limit," in *SPIE Proceedings on Generation, Amplification, and Measurement of Ultrashort Laser Pulses*, edited by Rick P. Trebino and Ian A. Walmsley (Bellingham, WA, SPIE - The International Society for Optical Engineering, 1994), pp. 184-194.

19. S. E. Harris, "Normal Modes for Electromagnetically Induced Transparency," *Phys. Rev. Lett.* **72**, 52-55 (January 1994).

20. B. E. Lemoff, C. P. J. Barty, and S. E. Harris, "Femtosecond-Pulse-Driven, Electron-Excited XUV Lasers in Eight-Times-Ionized Noble Gases," *Opt. Lett.* **19**, 569-571 (April 1994).

21. M. Jain, "Excess Noise Correlation Using Population Trapped Atoms," *Phys. Rev. A* **50**, 1899-1902 (August 1994).

22. C. P. J. Barty, C. L. Gordon III, B. E. Lemoff, P. T. Epp, and S. E. Harris, "Ultrashort Pulse Terawatt Lasers for the Generation of Coherent and Incoherent X-Ray Sources," in *Proceedings of Lasers '93* (to be published).

23. C. L. Gordon III, C. P. J. Barty, and S. E. Harris, "Time Gated X-Ray Imaging Using an Ultrashort Pulse, Laser-Produced-Plasma X-Ray Source," in *Proceedings of Ultrafast Phenomena IX*, Springer-Verlag (to be published).

24. S. E. Harris, "Refractive Index Control with Strong Fields," *Opt. Lett.* (to be published).

25. C. P. J. Barty, C. L. Gordon III, and B. E. Lemoff, "Multiterawatt 30-fs Ti:Sapphire Laser System," *Opt. Lett.* (to be published).

26. C. P. J. Barty, B. E. Lemoff, and C. L. Gordon III, "Ultrashort Pulse Multiterawatt Ti:Sapphire Laser System," in *Proceedings of Ultrafast Phenomena IX*, Springer-Verlag (to be published).

27. P. T. Epp and C. P. J. Barty, "Transmission Grating Masks for High Resolution Femtosecond Pulse Shaping," *Opt. Lett.* (submitted for publication).

28. B. E. Lemoff, G. Y. Yin, C. L. Gordon III, C. P. J. Barty, and S. E. Harris, "Demonstration of a 10-Hz, Femtosecond-Pulse-Driven XUV Laser at 41.8 nm in Xe IX," *Phys. Rev. Lett.* (submitted for publication).

29. A. Kasapi, M. Jain, G. Y. Yin, and S. E. Harris, "Electromagnetically Induced Transparency: Propagation Dynamics," *Phys. Rev. Lett.* (submitted for publication).

APPENDIX A

ABSTRACTS OF PUBLICATIONS

MeV X-Ray Generation with a Femtosecond Laser

J. D. Kmetec, C. L. Gordon, III, J. J. Macklin, B. E. Lemoff, G. S. Brown,[a] and S. E. Harris
E. L. Ginzton Laboratory, Stanford University, Stanford, California 94305
(Received 17 December 1991)

A 0.5-TW, 120-fs Ti:sapphire laser, when focused to greater than 10^{18} W/cm^2 onto a solid target, creates a plasma which emits radiation that extends beyond 1 MeV. The x-ray yield increases as the $\frac{3}{2}$ power of the incident laser energy, reaching 0.3% energy conversion to radiation above 20 keV at 40 mJ of laser energy on target. An x-ray spectral distribution of $1/E$ fits the data for most of the radiation, falling faster at higher photon energies.

PACS numbers: 52.25.Nr, 42.65.Re, 52.50.Jm

PHYSICAL REVIEW A VOLUME 46, NUMBER 1 1 JULY 1992

Dispersive properties of electromagnetically induced transparency

S. E. Harris, J. E. Field, and A. Kasapi
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305
(Received 20 January 1992)

An atomic transition that has been made transparent by applying an additional electromagnetic field exhibits a rapidly varying refractive index with zero group velocity dispersion at line center. A 10-cm-long Pb vapor cell at an atom density of 7×10^{15} atoms/cm^3 and probed on its 283-nm resonance transition has a calculated optical delay of 83 ns $[(c/V_G)=250]$.

PACS number(s): 42.50.Hz, 32.70.−n, 42.25.Bs, 42.65.An

PHYSICAL REVIEW A VOLUME 46, NUMBER 7 1 OCTOBER 1992

Studies of a 96.9-nm laser in neutral cesium

C. P. J. Barty, G. Y. Yin, J. E. Field, D. A. King, K. H. Hahn, J. F. Young, and S. E. Harris
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305
(Received 4 May 1992)

Investigations of a 96.9-nm laser in neutral cesium are described. Theoretical and experimental evidence is presented for the laser level designation and pumping mechanism. Measurements of the laser output are given, including saturated pulse energy, temporal profile, spatial profile, transition wavelength, gain cross section, and the variation of small signal gain with operating parameters. Comparisons of the temporal and spatial behavior of the 96.9-nm laser emission with respect to resonance line emission from ionic Cs are also presented.

PACS number(s): 42.55.Vc, 32.80.Dz, 42.55.Lt, 42.65.Re

IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 28, NO. 10, OCTOBER 1992

Ultrafast Laser Generation of Hard X-Rays

J. D. Kmetec

Invited Paper

Abstract—We have demonstrated efficient generation of X-rays above 20 keV when the tight focus of a 60 mJ, 120 fs laser is incident on a solid. We estimate 0.3% of the laser energy is converted to X-rays between 20 and 1000 keV when the target is solid tantalum. At least 10^6 photons above 1 MeV are generated with each shot. The X-ray yield is proportional to the Z of the target, and scales as the 3/2 power of the incident laser energy.

Generation of high-peak-power 20-fs pulses from a regeneratively initiated, self-mode-locked Ti:sapphire laser

B. E. Lemoff and C. P. J. Barty

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

Received June 15, 1992

We report the generation and measurement of 804-nm pulses with durations as short as 20 fs and with peak powers as high as 500 kW from a regeneratively initiated, self-mode-locked Ti:sapphire laser. Pulse duration is shown to decrease, and spectral content to increase, as intracavity power is increased. Control of intracavity focusing and a high-modulation-depth, acousto-optic modulator allow the intracavity power to be maximized. Cavity cubic phase error is minimized by correct design and placement of a group-velocity-dispersion-compensating prism pair.

116 nm H_2 Laser Pumped by a Traveling-Wave Photoionization Electron Source

S. J. Benerofe, Guang-Yu Yin and S. E. Harris
Edward L. Ginzton Laboratory
Stanford University
Stanford, CA 94305 USA

We discuss the use of a photoionization electron source (PES) to pump a 116 nm laser in the Werner band ($C^1\Pi_u \rightarrow X^1\Sigma_g^+$) of molecular hydrogen. The laser is pumped by free electrons which are created by photoionizing molecular hydrogen with soft x-rays from a traveling-wave laser plasma. The pumping configuration presented has allowed 2 Hz operation and saturation of the 116 nm Werner band laser. Using PES pumping we have measured a small signal gain coefficient of 1.6 cm^{-1}, an improvement of more than a factor of 10 over previously reported e-beam and discharge pumped results. We also report results showing that the small signal gain coefficient can be increased by cooling the laser medium, thereby reducing the Doppler width of the laser transition. We show that even though the free electrons have an average temperature of ~10 eV, the lasing hydrogen molecules retain an ambient temperature of < 0.02 eV. We measure an extrapolated small signal gain of exp(43), with a 1064 nm pump energy of 580 mJ in 200 psec.

ULTRASHORT HIGH PEAK POWER LASERS AND GENERATION OF HARD INCOHERENT X-RAYS

C. P. J. Barty, C. L. Gordon III, J. D. Kmetec, B. E. Lemoff and S. E. Harris

Edward L. Ginzton Laboratory
Stanford University
Stanford, California 94305

Abstract

The design, construction, and use of high peak power infrared laser pulses for the generation of diagnostic (20 keV to 150 keV) x-rays are discussed. A review of recent laser-plasma generation of diagnostic x-rays is presented. The advantages of such sources include subpicosecond pulse duration and extremely small source size. Because of their short duration, it should be possible to form time-gated medical images with up to eight times less x-ray flux than with conventional x-ray sources. Details of a next generation laser driver are also presented. Generation of 20-fs pulses from a regeneratively initiated, self-mode-locked Ti:sapphire laser is described. Techniques for amplification of these pulses to peak powers of 5 TW are presented.

Generation, measurement, and amplification of 20-fs high-peak-power pulses from a regeneratively initiated self-mode-locked Ti:sapphire laser

C. P. J. Barty, B. E. Lemoff and C. L. Gordon III

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

ABSTRACT

We report the generation and measurement of 804 nm pulses with durations as short as 20 fs and with peak powers as high as 500 kW from a regeneratively initiated, self-mode-locked Ti:sapphire laser. Pulse duration is shown to decrease, and spectral content to increase, as intracavity power is increased. Control of intracavity focusing and a high-modulation-depth, acousto-optic modulator allow the intracavity power to be maximized. Cavity cubic phase error is minimized by correct design and placement of a GDD compensating prism pair. Methods for accurate determination of the pulse duration without assumption of pulse shape are discussed. Interferometric autocorrelation is accomplished with an interferometer which intrinsically balances dispersion and loss in each arm. Techniques for eliminating pulse distortions during amplification are also presented.

Design of a Quintic-Phase-Limited Amplification System for Production of Multi-Terawatt 20-fs, 800-nm Pulses

B. E. Lemoff, C. L. Gordon III, and C. P. J. Barty

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

Abstract

Design of a multi-terawatt amplification system based on reflective optics and capable of supporting sub-20 fs pulses is presented. Tests of a quintic-phase-limited expansion and compression system, which is key to this design, are also discussed.

Cubic-phase-free dispersion compensation in solid-state ultrashort-pulse lasers

B. E. Lemoff and C. P. J. Barty

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

Received August 31, 1992

We show that intracavity group-velocity dispersion compensation with the use of prisms composed of conventional optical materials can be accomplished while simultaneously eliminating the round-trip cavity cubic phase. The ability to compensate perfectly both second- and third-order dispersion exists for pulses whose central wavelengths lie within a range that depends on the prism and laser rod materials as well as on the prism angles. In the case of Ti:sapphire and $Cr:LiSrAlF_6$ lasers, Brewster prisms composed of readily available materials can be used to compensate for both group-velocity dispersion and cubic phase over much of the respective tuning ranges.

High-Order Harmonic Generation Using Intense Femtosecond Pulses

J. J. Macklin, J. D. Kmetec, and C. L. Gordon III
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305
(Received 21 September 1992)

Neon gas excited by 800-nm laser pulses (15 mJ, 125 fsec) at an intensity near 10^{15} W/cm^2 generates harmonics up to the 109th order. The appearance of successively higher harmonics as the laser intensity is increased is compared to recent calculations of the strong-field atomic response. Blueshifting of the laser and harmonic wavelengths indicates a small degree of ionization until the threshold for the highest harmonics (> 91st) is reached.

PACS numbers: 42.50.Hz, 32.80.Rm, 42.65.Ky, 42.65.Re

Electromagnetically Induced Transparency with Matched Pulses

S. E. Harris

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

(Received 20 August 1992)

We show that electromagnetically induced transparency in a dense media is not a Beer's law superposition of the single atom response. When an arbitrarily shaped pulse is applied to an ensemble of population-trapped atoms, the atoms will generate a matching pulse shape on the complementary transition and, after a characteristic distance, render themselves transparent.

PACS numbers: 42.50.Rh, 32.80.Dz, 42.50.Hz, 42.65.Ky

Observation of electromagnetically induced phase matching

Maneesh Jain, G. Y. Yin, J. E. Field, and S. E. Harris

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

Received February 16, 1993

We report the observation of electromagnetically induced phase matching in collisionally broadened Pb vapor. At a critical intensity at which the Rabi frequency of a dressing 1064-nm laser overcomes the Doppler broadening of the vapor, the generated four-frequency-mixing signal at 283 nm increases in a steplike manner by a factor of 59.

PHYSICAL REVIEW A VOLUME 47, NUMBER 6 JUNE 1993

Vacuum-Rabi-splitting-induced transparency

J. E. Field
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(Received 21 January 1992)

The vacuum Rabi splitting may be observed with population-trapping techniques. The trapped population has a lifetime much greater than the natural lifetime of the atomic transition: as a result, vacuum Rabi splittings that are much smaller than the natural lifetime may be observed. A condition for lasing without inversion in this system without any externally injected coherent field or coherence is stated.

PACS number(s): 42.50.Dv, 06.30.Lz, 42.50.Lc

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OPTICS
COMMUNICATIONS

Atomic scale temporal structure inherent to high-order harmonic generation

S.E. Harris and J.J Macklin
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and

T.W. Hänsch
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Received 20 January 1993

Using intense lasers, several laboratories have generated high-order harmonic spectra which are flat over 20 eV. If the harmonics are appropriately phased, this bandwidth corresponds to temporal pulses on the order of $\sim 5\times10^{-17}$ s, and thereby motivates a search for a new regime of short-pulse generation.

PHYSICAL REVIEW A VOLUME 48, NUMBER 3 SEPTEMBER 1993

Spontaneous emission into an electromagnetically induced transparency

J. E. Field and A. Imamoğlu
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(Received 22 August 1991; revised manuscript received 15 June 1992)

We investigate spontaneous emission into an electromagnetically produced transparency of the form recently proposed [A. Imamoğlu and S. E. Harris, Opt. Lett. 14, 1344 (1989)]. We show that the achievable radiation temperature (or brightness) at the transparency is much greater than the atomic temperature.

PACS number(s): 42.50.Hz, 32.80.Bx

Quintic-phase-limited, spatially uniform expansion and recompression of ultrashort optical pulses

B. E. Lemoff and C. P. J. Barty

Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

Received April 15, 1993

Design of an expansion and recompression system for amplification of sub-20-fs optical pulses to multiterawatt peak powers is presented. The system allows one to eliminate spatial inhomogeneities and cubic and quartic phase errors that make existing designs unsuitable for use with pulses much shorter than 100 fs. We experimentally demonstrate >10,000 times expansion and recompression of ~25-fs optical pulses.

Invited Paper

Multiterawatt Amplification of Ultrabroadband Optical Pulses: Breaking the 100 fs Limit

C. P. J. Barty, B. E. Lemoff, C. L. Gordon III and P.T. Epp

Edward L. Ginzton Laboratory, Stanford University
Stanford, California 94305

ABSTRACT

A first of its kind, multiterawatt, ultrashort pulse laser system is described. The system is capable of producing 125-mJ, 35-fs, 800-nm pulses with near diffraction limited beam quality at a 10 Hz repetition rate. Methods for control of phase and amplitude distortion during sub-100-fs amplification are presented.

Normal Modes for Electromagnetically Induced Transparency

S. E. Harris

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(Received 19 July 1993)

We define paired variables which are the normal modes for electromagnetically induced transparency and use these modes to study the propagation of matched pulses in an absorbing medium.

PACS numbers: 42.50.Rh, 32.80.Dz, 42.50.Hz, 42.65.Ky

Femtosecond-pulse-driven, electron-excited XUV lasers in eight-times-ionized noble gases

B. E. Lemoff, C. P. J. Barty, and S. E. Harris

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Received November 22, 1993

We propose three XUV laser schemes in the 30–50-nm wavelength region that can be driven by 10-Hz ultrashort-pulse terawatt laser systems. Tunneling ionization by circularly polarized radiation produces both the ions and hot electrons necessary to excite the upper laser level.

BRIEF REPORTS

Brief Reports are accounts of completed research which do not warrant regular articles or the priority handling given to Rapid Communications; however, the same standards of scientific quality apply. (Addenda are included in Brief Reports.) A Brief Report may be no longer than 4 printed pages and must be accompanied by an abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.

Excess noise correlation using population-trapped atoms

Maneesh Jain
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(Received 24 November 1993)

We study the behavior of two quantized fields interacting with atoms in a coherent population-trapped state. It has recently been shown that such a system generates fields with matched envelopes as well as matched photon statistics. These effects have an important consequence: the matching of any excess noise input at the two channels of the system. We explicitly show the generation of correlated excess noise by a population-trapped atomic system and how this effect may be used to suppress the excess noise and enhance the carrier-to-noise ratio of optical sources.

PACS number(s): 42.50.Gy, 42.50.Ct, 42.50.Lc, 42.65.Ky

ULTRASHORT PULSE TERAWATT LASERS FOR THE GENERATION OF COHERENT AND INCOHERENT X-RAY SOURCES

C. P. J. Barty, C. L. Gordon III, B. E. Lemoff, P. T. Epp and S. E. Harris

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Abstract

The construction of a new class of terawatt laser systems which operate with pulse durations of ~30 fs is described. Planned experiments with this system to generate sub-picosecond diagnostic x-rays and to generate coherent sources in the 10 nm to 100 nm range are discussed.

Time Gated X-Ray Imaging Using an Ultrashort Pulse, Laser-Produced-Plasma X-Ray Source

C. L. Gordon III, C. P. J. Barty, and S. E. Harris
Edward L. Ginzton Laboratory, Stanford University, Stanford, California 94305

Abstract. A method for x-ray exposure reduction in medical imaging is discussed. This method uses an ultrashort pulse, laser-produced-plasma x-ray source and a time gated microchannel plate detector to reduce scattered radiation at the detector.

Refractive Index Control with Strong Fields

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ABSTRACT

We describe an EIT-like effect which allows a strong laser to control and reduce to unity the refractive index of a weak probe. We consider a lossless multi-state system with all states far from resonance.

Multiterawatt 30-fs Ti:sapphire Laser System

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Abstract

A near-diffraction-limited and transform-limited, multiterawatt laser system which produces ~30-fs, 125-mJ, 800-nm pulses at a repetition rate of 10 Hz has been constructed. Methods for the control of femtosecond time-scale phase and amplitude distortions have been developed and implemented.

Ultrashort Pulse Multiterawatt Ti:sapphire Laser System

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Abstract. The development of a new class of compact, ultrashort pulse, multiterawatt laser systems is described. Tests of a 4 TW, ~30 fs, 10-Hz system which is both diffraction and bandwidth limited are presented.

Transmission Grating Masks for High Resolution Femtosecond Pulse Shaping

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Abstract

A high-resolution, variable-amplitude spectral filter is described. The filter is based on microlithographically etched transmission gratings and is suitable for applications in which a constant spectral filter is desired. Tests of masks designed to control gain narrowing in a multiterawatt, ultrashort pulse amplification system are presented.

Demonstration of a 10-Hz, femtosecond-pulse-driven XUV laser at 41.8 nm in Xe IX

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ABSTRACT

We report the observation of a gain of approximately exp(11) at 41.8 nm in eight-times-ionized xenon. This XUV laser is driven by a 10-Hz, 70-mJ circularly-polarized femtosecond laser pulse. The laser is focused into Xe at pressures ranging from 5 to 12 torr. The laser is collisionally excited, with both the ions and electrons produced by field-induced tunneling.

PACS numbers: 32.30.Rj, 42.55.Vc, 42.60.By, 52.50.Jm

Electromagnetically Induced Transparency: Propagation Dynamics

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Abstract

We describe the temporal and spatial dynamics of propagating EIT pulses in an optically thick medium. Results include pulse velocities as slow as $c/165$ with 55% transmission, the probable observation of adiabatons, and the observation of near diffraction-limited transmitted beam quality.

42.50.Gy, 42.50.Hz, 32.80.-t